ONTARIO
DEPARTMENT OF MINES

NOTES ON
ZINC-LEAD MINERALIZATION IN SILURIAN DOLOMITE
OF THE
NIAGARA ESCARPMENT AND BRUCE PENINSULA, ONTARIO

by

G. R. GUILLETT

Miscellaneous
Paper: MP. 8

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Zinc - Lead Mineralization in Silurian Dolomite[1]

By G. R. Guillet[2]

The following notes have been extracted from various sources, and pertain to the widespread occurrence of sphalerite and galena in Paleozoic rocks. They have been prepared in response to public interest in recent announcements (The Northern Miner, January 26, 1967) concerning zinc mineralization on the Bruce Peninsula. Although not proven to be extensive, the Ontario occurrences are nevertheless essentially similar to the important deposits of the Mississippi Valley, U.S.A., and Pine Point, N.W.T.

Guelph - Lockport - Amabel Formations

South-central and southwestern Ontario are underlain by Cambrian, Ordovician, Silurian, Devonian, and Mississippian rocks. The table of formations is summarized as follows (Hewitt 1966, p.3).

SYSTEM	FORMATION OR GROUP	LITHOLOGY
Mississippian	Port Lambton Formation	Grey to black shale, sandstone
Devonian	Kettle Point Formation	Black shale
	Hamilton Formation	Grey shale and argillaceous limestone
	Delaware (Dundee) Formation	Limestone
	Columbus Formation	Sandy limestone and dolomite
	Detroit River Group	Brown limestone and dolomite
	Bois Blanc Formation	Limestone, dolomite, chert, sandstone
	Oriskany Formation	Sandstone
Silurian	Bertie-Akron (Bass ls.) Formation	Buff dolomite
	Salina Formation	Dolomite, shale, gypsum, salt
	Guelph-Lockport-Amabel Formations	Dolomite
	Clinton-Cataract Groups	Shale, sandstone, dolomite, limestone

1 Manuscript received by The Director, Geological Branch, 9 Feb. 1967.
2 Geologist, Ontario Department of Mines, Toronto.

SYSTEM	FORMATION OR GROUP	LITHOLOGY
Ordovician	Queenston Formation	Red shale
	Meaford-Dundas Formations	Grey shale
	Collingwood Formations	Grey to black shale
	Trenton-Black River Groups	Limestone
Cambrian	Potsdam (Nepean) Formation	Sandstone

Silurian dolomites of the Guelph - Lockport - Amabel Formations form the cap rock of the Niagara Escarpment, providing a striking topographic feature from Niagara Falls to Manitoulin Island. Throughout this belt of rocks traces of sphalerite and galena have been found replacing fossils and filling minute fractures and vugs.

Guelph Dolomite overlies Lockport Dolomite in the south and Amabel Dolomite in the north. A facies change in the vicinity of Waterdown marks the transition from Lockport to Amabel, the two formations being equivalent in time.

Hewitt (1966, p.6) describes the formations as follows:

> The Lockport Dolomite, which overlies the Clinton Group, is divided into three members in ascending order: Gasport Dolomitic Limestone, Goat Island Dolomite, and Eramosa Dolomite. The Amabel Formation is 131 feet thick at the type section at Wiarton and consists of a dense blocky dolomite at the base called the Lions Head Member; a massive, sugary dolomite, the Colpoy Bay Member; a blue-grey mottled, fine- to coarse-grained dolomite, the Wiarton Member; and a thin-bedded brown bituminous dolomite, the Eramosa Member (Bolton 1957, p.51).
>
> The Guelph Formation, which overlies the Lockport and Amabel, is a buff-coloured, fine-grained sugary dolomite usually of high purity. The combined thickness of Guelph-Lockport and Guelph-Amabel dolomites ranges from about 200 feet in the Niagara Peninsula to over 400 feet in the Bruce Peninsula.

Lead - Zinc Occurrences

Williams (1919, p.102-103) mentions the widespread occurrence of sphalerite and galena, and describes the principal showing near Wiarton as follows:

Small particles of galena and sphalerite, or zinc blende, are widely scattered through the Niagara and Guelph dolomites. Particles of galena may be found in the Lockport dolomite at the top of the falls at Grimsby, at Rockwood, and east of Guelph. Zinc blende may be seen at Rockwood and elsewhere.

The only notable amount of zinc blende reported, however, was discovered by Dr. Wolverton of London, on lot 30, concession II, Albermarle East township, Bruce peninsula, about 4 miles northwest of Wiarton. Under the direction of Mr. G.B. Bourne considerable prospecting has been done since 1910, an excavation having been made measuring approximately 30 feet in length, 10 feet wide, and 25 to 30 feet in greatest depth (not 100 feet by 30 feet by 30 feet, as reported in the Summary Report, 1912, page 281). The rock is massive, very scraggy, and full of pore spaces and cavities, and when fresh is a light blue colour. The large amount of pore spaces and cavities is principally due to the solution of fossils which are large and numerous, some of the cephalopods being over 1 foot long and 6 inches in diameter. The zinc blende occupies these cavities, the mineral in some cases partly replacing fossils. The action of surface waters has in some cases caused a concentration of pieces of zinc blende at the bottom of small pockets, into which the blende has fallen on being released from the rock by solution of the dolomite to which it was attached. About 110 pounds of loose blende is said to have been obtained in such a pocket, where it was mixed with soil and pieces of rock. The ore continues down to a depth of 20 feet, below which no ore has been found.

A shipment of several hundred pounds of this ore was made previous to 1912, the lot being said to assay 69.76 per cent zinc. When last visited (September 1916) about two cords of hand-picked ore was piled up alongside the prospect.

The zinc blende occurs in dolomite of lower Guelph age, closely related in fauna to the Racine beds of Wisconsin. Not far below the zinc deposits is the top of the Eramosa, arenaceous dolomite forming the upper division of the Lockport formation. These beds, because of their fine-grained, impervious nature have doubtless prevented downward movement of the surface waters, which on this account moved entirely in a lateral direction, dissolving such minerals as zinc blende under favourable conditions for solution and precipitating them where numerous pore spaces and cavities existed owing to the solution of fossils. The accumulation in local pockets is doubtless very recent, and due to surface solution.

Williams and others have mistakingly located the occurrence in concession II; actually it is in the west part of lot 30, concession III east, Albermarle township, Bruce county.

Sabina (1964, p.130-131) mentions the occurrence as a mineral-collecting area, and describes the sphalerite and the location of the main pit as follows:

Golden-brown to dark-brown resinous sphalerite occurs in pore spaces and cavities and partly replaces fossils in Amable dolomite exposed by a series of pits throughout the Bruce Peninsula, from Wiarton to Cabot Head.

A twinned crystal of sphalerite from this area has been fashioned into a 6-carat brilliant cut stone. The sphalerite-bearing dolomite rock takes a good polish and is well suited for larger ornamental objects, such as book-ends, paper-weights, etc.

To reach one of the more accessible pits, proceed north from Wiarton along Highway No. 6 for 4½ miles and stop just after passing over the crest of a ridge. At the base of the hill on the east side of the highway there is a clearing in the wooded area. A trail leads from the clearing in an easterly direction along the north flank of the ridge. Follow this trail and, where it branches off in two directions, take the south fork which leads to a pile of broken-up rock. The pits are in the woods just beyond the rock pile. The total walking distance from the highway is ¼ to ½ mile.

The following report by Gibson (1915, p.151) describes activities on the Wiarton property during 1914:

On lot 30 in the second concession of the township of Albemarle in Bruce county, the Albemarle Zinc Company continued to prospect its property during the year. Work was begun during the summer of 1910, and in 1911 a small shipment of sphalerite was made to Cleveland.

On the date of inspection in August, two men were engaged in trenching, and cleaning out an open pit, which measured 20 feet by 12 feet by 30 feet in depth.

The ore is zincblende, occurring in small pockets in the lime carbonates.

The plant consisted of one 15-h.p. portable boiler, one Rand drill, and a hand winch.

George Bourne, Wiarton, was in charge of the work.

In marginal notes accompanying preliminary maps of the Owen Sound area, Caley (1945) commented on zinc occurrences as follows:

The presence of small amounts of zincblende in Bruce Peninsula has been known for many years. Excavations for the mineral were made about 1910 on lot 30, con. 3, east, Albemarle tp., and, prior to 1912, a shipment of "several hundred pounds" of ore, said to assay 69.76 per cent zinc, was made. About 1936 prospecting for zinc blende was done on lots 8 and 9, cons. 10 and 11, St. Edmund tp., where several small pits and trenches were made, and in 1943 another pit was opened at the same general locality. It is not known whether any zinc was taken from these workings. The mineral occurs as scattered crystals, and as partly replacing fossils, notably corals. Wherever seen, it occurs near the base of the Guelph formation.

Characteristics of the mineralization in the Bruce Peninsula were outlined in the Northern Miner (January 26th, 1967):

The zinc occurrences are most unusual representing a type that heretofore have not been found in Canada but they have their counter-part in the Mississippi Valley where extensive deposits are mined. The Bruce Peninsula zinc occurs as sphalerite (a zinc sulphide) which is a replacement in the sedimentary rocks of the region - limestone and dolomite and slates.

The best showings are in what the geologists refer to as a giant bioherm, which is a coral reef formed in the ancient seas and now enclosed in limestone and dolomite.

The zinc occurrences are most unusual and commonly replace the fossils and coral, although some plates and veinlets of sphalerite are seen in the rock. The fossil forms, such as crinoid stems and cephalopods are clearly recognizable. The reef areas are a great jumble of coral, fossil plants and shells. But, there are other occurrences such as in one pasture where flat slabs of dolomite are exposed and cemented to it are balls up to 10 ins. in diameter. These balls, which are replaced with zinc are scattered haphazardly across the surface, a matter of several feet apart. At first it was thought that these balls represented the replacement of zinc in fossil sponges, but other opinion is that they are more likely concretions. Although it is doubtful if this particular showing would make ore it will undoubtedly arouse great interest and curiosity among geologists and mineralogists. And, it is certainly a spot that requires investigation to see what else might occur in the vicinity.

The zinc (sphalerite) is often very difficult to distinguish from the surrounding rock, but being more resistant to weathering it stands out and can often be recognized by feel. The reefs, too, are also more resistant to weathering and stand out as topographical features. Color of the zinc varies from light amber to dark brown but it also shows veriations of white, pink, yellow and blue. It is commonly accompanied by a halo of bleaching and if the zinc itself is white it is easily understandable why it is completely unrecognizable to the uninitiated.

Bolton and Liberty (1966, p.147) mention a new showing in the Bruce Peninsula:

A new sphalerite showing was confirmed 7½ miles south of Ferndale on the east side of Highway 6 within the Eramosa Member of the Amabel Formation. This find will be more fully described in a forthcoming Geological Survey memoir by T. E. Bolton, J. F. Caley, and B. A. Liberty, entitled "Palaeozoic Geology of Bruce Peninsula District". It was determined to be of a different type of occurrence from those in Albemarle and St. Edmund townships.

The presence of sphalerite and galena in various places along the outcrop belt of the Silurian dolomites has been known for many years. Referring to the dolomites of the southern part of the belt, between Niagara and Ancaster, Logan et al (1863, p.324-325) reported:

They are highly bituminous, and for the most part magnesian for the whole distance; and they abound in fine cabinet specimens of selenite, celestine, pearl-spar, blende, and galena. Crystals of the latter mineral exist in greater or less quantity, in nearly all the limestones from the Pentamerus band to the summit of the upper beds; but they are in the greatest abundance in the latter, especially in the township of Clinton, near the village of Beamsville, where an unsuccessful attempt was made by Mr. Lee to establish a lead mine upon what was supposed to be a lode, on a lot of the

eighth range of the township, which is the property of Mr. R. Comfort. The supposed lode, however, appears to be rather one of the open joints or fissures, running E. and W., by which these rocks are intersected in many places. In the locality in question, the fissure, which is filled up with drift, is crossed by small cracks, the walls of which are invested with crystals of pearl-spar and galena. The ore is also seen on each side of the main fissure, and is moreover disseminated throughout the limestone, near the fissure.

Thomson (1952) also reported on the Beamsville occurrence as follows:

The showings have been examined at various times and developed by a few small test-pits and a shallow rock quarry. In the summer of 1951 an attempt was made to evaluate the commercial possibilities of the lead and zinc combined with the marketing of the dolomitic host rock. This project was under the direction of C.H.E. Stewart, mining engineer of Toronto. The main showings are located on the farms of Dan High on lots 18 and 19, Concession VIII, Clinton township, and Anthony Mulec who lives immediately to the west on lots 20 and 21.

Much of the information given below was obtained from a report by C.H.E. Stewart, mining engineer, of Toronto, covering the work on the showings in 1951.

GEOLOGY

The geology of the area is shown on the Toronto - Hamilton sheet (Map 584A) of the Geological Survey of Canada. The showings are on farmland located on the top of the Niagara escarpment. The bedrock is Lockport dolomite which strikes east westerly and dips very gently to the south. The rock is massive and the beds appear to be fairly thick.

Crystal and tiny stringers of galena are sparingly distributed in a very erratic fashion throughout the dolomite, apparently over quite a large area. At least four areas show the characteristic spotty mineralization and these are spread over an irregular area about 4,500 feet long and up to 500 feet in width. Little is known about the vertical extent of the mineralization but the different exposures probably represent only a limited horizon near the top of the Lockport beds. The galena crystals and lumps often occur in vugs and cavities in the dolomite. There are also patches of galena in stringers that occupy minute fractures in the dolomite. Little sphalerite is seen compared to galena and it is surprising that the analyses show the ratio of zinc to lead to be about 4 to 1. The zincblende is honey coloured and therefore not so apparent on visual inspection. Much of the rock is devoid of mineralization. There is no apparent structure or zones of alteration with which the mineralization could be associated. The best concentrations of galena appear to be around the shallow quarry on the farm of Dan High and near the old test-pits on the Mulec location. At some points galena crystals are fairly numerous. Around the edge of the quarry approximately one-third of the rock slabs broken will show some indication of galena on the fresh exposure.

EVALUATION

The mineralization is so erratic and sparse that only bulk sampling can give an accurate appraisal of the average grade of the deposit. Visual inspection shows that it is a very low grade lead zinc occurrence and could only be of possible economic interest as a large tonnage open-cut operation in which the dolomite could be marketed along with the metallics.

In 1951 two test-pits were sunk at points approximately 1400 feet apart. Bulk samples were taken from each pit under the supervision of C.H.E. Stewart. These were shipped to the Bureau of Mines, Ottawa, where they were crushed to ½ inch size, sampled, and assayed. Bulk sample No. 1, weighing 6.5 tons, was slashed off the wall of an old test-pit, 8 feet deep, on the farm of Anthony Mulec. Six analyses of the bulk sample, made by three different assay offices, showed only traces of lead. Then a 500-pound sample, which had been retained by the Bureau of Mines for testing purposes, was concentrated on a Wilfley table and the concentrates assayed. From this test it was calculated that the average metal content of the 500-pound sample was 0.12 percent lead and 0.47 percent zinc.

Bulk sample No. 2 was taken from the shallow quarry on the farm of Dan High; this weighed 5.5 tons. An average of six assays of the crushed and sampled rock was 0.025 percent lead and 0.647 percent zinc. A table concentrate of this sample was also made and from the results obtained the metal content of the rock was calculated to be 0.09 percent lead and 0.41 percent zinc.

Samples of the richest galena mineralization from the above-mentioned localities were taken by the writer and assayed for silver with negligible results. A complete spectrographic analysis also showed nothing of interest.

Referring to the Goat Island Member of the Lockport Formation, Bolton (1957 p. 49) reported that "Vugs filled with calcite, gypsum, fluorite, and sphalerite are numerous, particularly in the Niagara Falls area."

The Dundas quarry of Canada Crushed and Cut Stone Limited in West Flamboro township is well known among mineral collectors as a source of fine crystals of sphalerite, galena, celestite, fluorite, and calcite.

The Guelph - Lockport - Amabel dolomites are the major source of crushed stone in the Toronto-Hamilton area. According to Hewitt (1966 p. 6):

These formations are extensively quarried for crushed stone and fluxstone at Thorold, St. Catharines, Vineland, Vinemount, Stoney Creek, Dundas, Nelson, Milton, Georgetown, Acton, and Duntroon. They are quarried for building stone at Queenston and Wiarton, and for the manufacture of dolomitic lime at Guelph, Hespeler, and Rockwood (Hewitt 1960, 1964a, 1964b).

It is interesting to note that trace metal studies by Warren and Delavault (1961, p. 1271) on chip samples from these and other limestone and dolomite quarries in southern Ontario show the Lockport Dolomite, but not

the Amabel, to have a far higher lead and zinc content than any other formation.

SYSTEM	FORMATION OR GROUP	NO. OF SAMPLES	PARTS PER MILLION Pb	Zn	Cu
Devonian (Middle)	Bois Blanc	4	3	18	6
Silurian (Upper)	Bertie Akron				
	Shaly dolomite	5	18	28	8
	Other members	11	3	11	6
(Middle)	Lockport				
	Amabel	5	6	14	6
	Eramosa, Goat Island, Gasport Members	8	65	520	8
Ordovician (Middle)	Trenton	11	4	13	6
	Black River	55	4	15	8
(Lower)	Beekmantown				
	Oxford	10	16	43	13
	Marsh	3	9	24	20

Lead - Zinc Deposits of the Mississippi Valley

Sphalerite and galena occurrences in the Silurian Dolomites of Ontario have characteristics most like those of the Mississippi Valley and Pine Point deposits. Bateman (1950, p.320, 532-535) describes the Mississippi Valley deposits as follows:

> The Mississippi Valley region constitutes a large zinc-lead metallogenetic province where zinc and lead ores occur in the 500 miles from Wisconsin to Oklahoma. The deposits are cavity fillings and replacements and are not in direct association with known igneous rocks, although present knowledge indicates magmatic affiliations. Minerals other than sphalerite and galena, with lesser pyrite or marcasite, are rare. This province is the largest lead-zinc producing area in the world. Most of the production comes from the Tri-State, Joplin, and southeastern Missouri areas. The Tri-State area has for the last 50 years yielded 50 to 80 percent of the United States production and 20 to 30 percent of the world production.
> Southeastern Missouri; This district, centering around Flat River, also called the "lead belt," is the greatest lead district in the world. Discovered in 1720 and productively mined in 1800, it yields annually up to 180,000 tons of lead with a little silver.
>
> The deposits occur chiefly as disseminated replacements in the flat-lying Bonneterre dolomite of Cambrian age. They lie at shallow depth, within a vertical range of 200 feet, and average 10 to 15 feet in thickness, 200 to 300 in width, and 1,000 feet or more in length.

Hundreds of acres are underlain by such flat ore bodies, disturbed here and there by small faults.

Galena, the only important ore mineral, occurs in disseminated grains and crystals up to an inch across. Marcasite is abundant, and minor siegenite (cobalt-nickel sulphide), chalcopyrite, and pyrite are observed, along with a little calcite, glauconite, and dickite.

Tri-State District. This broad district, centering around Joplin, Missouri, is not only the greatest zinc district of the world, but it yields the lowest-grade zinc ores. Some lead is recovered but no other metals. Its remarkable waste dumps, dotting the flat surface like sand dunes on a desert, attest to the extensiveness of the underground workings.

Its area is some 2,000 square miles, and it has yielded over 900 million dollars in metals.

The geology is relatively simple. Nearly flat-lying sediments include the Boone formation, which is separable into 16 beds and is the host rock of the ores. It is unconformably overlain here and there by uneroded patches of Pennsylvanian shale. Beneath the pre-Pennsylvanian erosion surface a karst topography was developed, with sinkholes, underground drainage channels, and caves, in the underlying limestone and particularly along the Grand Falls chert member. Chert and jasper beds are numerous in the Boone. Roy concludes that there is an earlier sedimentary chert and later hydrothermal chert and jasper. Two prominent faults are known, one of which is mineralized. Also, according to Fowler, there are prominent shear zones that brecciated the cherts and localized the ores. These structures appear to be related to major structural features of the Mississippi Valley. Fowler states that the Boone beds are barren of ore except where deformation has created favourable structure for ore. There are no igneous intrusives near the ore.

The deposits consist of (a) runs and circles of ore near the surface, and (b) sheet or blanket ore along the Grand Falls chert. The first are the most productive. The runs fill and follow shallow solution channels along cherty horizons. They range from 10 to 300 feet in width and are as much as 80 feet thick and 2 miles long. The circles encircle sinkholes and attain dimensions of 800 by 650 feet; the ore is deposited in thicknesses up to 30 feet, around fragments of slumped chert. The sheet ground, which may be 15 feet or more thick, is in the Grand Falls chert where the limestone has been removed from around the chert nodules.

The minerals consist chiefly of zincblende and subordinate galena with minor amounts of wurtzite, marcasite, pyrite, and chalcopyrite. Enargite and millerite have also been identified. The gangue minerals are quartz, chert, carbonates, and a little barite. There is also a large group of oxidation products. The minerals occur in definite sequence.

Generally similar ores are scattered over the upper Mississippi Valley, particularly in Wisconsin. These ores, now largely exhausted, occur mainly as fillings of caves, pitches and flats, and solution joints in the Galena limestone. They also probably have a hydrothermal origin.

The ore deposits of the Upper Mississippi Valley, considered by many to be most nearly like the Ontario occurrences, are further described by Lindgren (1928, p.486-487):

Upper Mississippi Valley: The districts of the upper valley lie in Wisconsin, Iowa, and Illinois. The important districts are in Wisconsin and Illinois and yielded in 1925 about 1,900 short tons of lead and 20,000 tons of zinc. The ore deposits are found in Ordovician strata of almost horizontal position. The following formations are recognized:

	Feet
Cincinnati or Maquoketa shale	160
Galena dolomite	240
Platteville limestone (Trenton)	55
St. Peter sandstone	100
Lower magnesian limestone	350

Below the magnesian limestone is 700 feet of the Cambrian Potsdam sandstone. The so-called "oil rock," a thin bed of bituminous shale, is found at the base of the Galena formation or at the top of the Trenton. The rocks dip gently southwest and are flexed into very shallow troughs.

The ores are confined to the Galena limestone and the upper part of the Platteville limestone; the minerals consist of marcasite, sphalerite, and galena, deposited in the order noted. The gangue is crystallized calcite, rarely barite. Cadmium is absent, but a trace of silver is found. The abundance of marcasite causes metallurgical difficulties and necessitates treatment of the concentrates in electrostatic or magnetic separators, in the latter case preceded by partial roasting. The ores occur as fillings of open spaces, vertical crevices, or "gash veins" connected with "pitches" or "flats," all probably due to solution along joint planes.

Stalactites of sulphides are sometimes found indicating that the spaces were not always filled by solutions. In part there are also flat bodies of disseminated ores. The galena predominates near the surface, probably largely because the zinc blende has been dissolved as sulphate and transformed to silicate or carbonate in the lower levels. In depth zinc blende with a little galena is the principal ore. Mining operations extend to a depth of at most 200 feet. The distribution of the oil shale, according to Bain, seems to coincide with the extent of the deposits. Cox, however, holds that the metal was derived from the overlying Maquoketa shale and carried down to be concentrated in the Galena limestone.

Origin of Mineralization

Mineralization of the Mississippi Valley-type ores has been ascribed to both hydrothermal and meteoric origins. Both views are still strongly supported in the United States, but there is a tendency to favour a meteoric origin in Canada.

The American view is given by Bateman (1950, p.533) as follows:

The deposits are not associated with observable igneous intrusives, and because of this they have been regarded as the products of meteoric waters. However, the mineralogy indicates a hydrothermal origin, as maintained by Tarr, from an undisclosed igneous source, the solutions passing through

fissures, depositing a little galena in the underlying LaMotte sandstone, and spreading through the Bonneterre dolomite. These ores represent, therefore, low-temperature deposition (probably in late Cretaceous time) and illustrate widespread, lateral, selective penetration of beds by mineralizing solutions uncontrolled by obvious openings, just as in the puzzling cases of the Rhodesian copper deposits and the Rand gold reefs.

Concerning the Ontario occurrences, Liberty (1966, p.7)

..... favours an origin related to the known reefal growth in the Amabel-Guelph (Niagaran) strata. The hypothesis concerns extraction of the zinc from the Amabel (Lockport) sediments by reefal circulating waters and deposition of the zinc sulphide where brecciation, cavities, and pore space in the reef rock permit favourable temperatures and pressures. This explanation is supported by: the presence of mineralized fossil remains, stratigraphic restriction of mineralization, mineralization of low permeability rocks, simple mineralogy, low temperature of deposition, lack of evidence of igneous activity and apparent lack of migration routes, i.e. faults, for hydrothermal solutions. With the reefal growth being so very extensive, with zinc mineralization being known at many localities associated with reefs, and with mineralization being found at three localities in the map-area, the writer considers more prospecting to be warranted.

Extraction of the zinc by circulating ground waters from the Lockport sediments is supported by the work of Warren and Delavault (1961, p.1270) previously mentioned. Trace metal studies on various dolomite samples showed the Lockport to have "a far higher lead and zinc content than any other formation."

Concerning Mississippi Valley - type deposits in general, and the Pine Point deposits in particular, Jackson (1966) ascribes the mineralization to connate waters, in which the metals are carried as chlorides and sulphides, having been extracted from the sedimentary pile. The Pine Point deposits occur in the reefal, very porous, coarsely crystalline dolomite of the Middle Devonian Presqu'ile Formation.

Reef Structures

The association of lead-zinc ores with reef structures is amply demonstrated in most Mississippi Valley - type deposits. The following notes are taken from Jackson (1966, p.11-12) and refer to broad structural features, dolomitization and porosity, and reef structures in particular:

"Nearly every Mississippi Valley type ore body is associated with a permeable layer or zone in the rock. The deposits are commonly associated with a zone of tectonic or sedimentary breccia, a reef or bank development, or, as in the case of Missouri, the pinchout of the underlying permeable sandstone. Dolomitized reef core facies with high porosity and permeability are host to many of the Alpine ores.
..... Dolomitization, porosity and permeability are intimately linked in a carbonate environment. In general, porosity tends to be enhanced by complete dolomitization, and the lead-zinc ore bodies lie mainly within such dolomitized zones or layers.
..... Reefs in particular, can provide the sedimentary environment (back-reef lagoon) for direct precipitation of some lead-zinc ores, and also the more porous areas within the reefs may later serve as the route through which fluids can escape during the dewatering of associated sediments.
..... Most striking among the structural features associated with lead-zinc ore bodies is the location of the mineralization near margins of sedimentary basins and the edges of major synclines."

Hewitt (1960, p.172-173) gives a brief description of reefs and their characteristics, and outlines their occurrence in the Amabel and Guelph formations:

Types Of Reefs

Reefs essentially consist of, and are built up by, sedentary colonial organisms such as corals, stromatoporoids, crinoids, and algae. Two types of reef structures are recognized in Ontario:

1. Biostrome: a lens-like, tabular sheet of massive, porous reef rock rarely over 15 feet thick, composed of sedentary organisms (corals, crinoids, stromatoporoids, etc.) in a normal bedded rock of different lithological character.
2. Bioherm: a mound-like or dome-like mass or core of massive, porous reef rock, composed of sedentary organisms, surrounded by normal bedded rock of different lithological character that dips off the reef mound at high angles.

Recognition And Characteristics Of Reefs

Reef rock may be recognized by the following features:

1. Reef rock has a different texture, structure, and lithology than the surrounding rock.
2. Reef rock is composed of corals, stromatoporoids, algae or crinoids and is normally highly fossiliferous.

3. The reef is composed of massive porous rock lacking the bedding of the surrounding rock.

4. The biohermal type of reef is distinguished by its mound-like structure with the reef flank beds dipping off the mound at steep angles.

Reefs range in size from 200-300 feet to over ½ mile in diameter. Biostromes are rarely over 15 feet thick, while bioherms range from 20 to 70 feet in height. In exceptional cases, pinnacle reefs in the Guelph formation of southwestern Ontario (subsurface) stand up 200-300 feet in height.

Occurrence Of Reefs In Southern Ontario

Amabel Formation Of Silurian Age

The Amabel formation of Silurian age, which is the lateral equivalent of the Lockport dolomite in the Waterdown-Georgetown-Bruce Peninsula area, is characterized by the abundance of reef rock. Biohermal reefs a few hundred feet in diameter and 50-60 feet in height are very common, and are identified by the massive structure of the reef rock and the reef flank beds dipping off the mounds. Since the Amabel dolomite is normally of high purity, the reef rock is not greatly different in composition from the enclosing strata but will be highly porous, probably softer and less durable, and may have clay pockets and iron staining, particularly near the surface.

Guelph Dolomite

Reefs have been observed in the Guelph formation in the Guelph-Hespeler area. Here the Guelph formation is normally of very high purity, and the reef facies, although of high purity (under 3 percent impurities), may contain more impurities than the inter-reef dolomite. Due to the coarser crystallinity and higher porosity, together with clay pockets, discolouration, and iron staining, which is prevalent in the reef rock, the reefs may be not as desirable for lime manufacture as the more uniform and often extremely high-purity inter-reef dolomite.

Liberty (1966, p.4) mentions the abundance of reefs in the Amabel and Guelph formations on the Bruce Peninsula as follows:

"The Amabel Formation is in reality a reefal complex, presenting biostromal, biohermal, and interbiohermal (interreef) facies. Thickness of the formation is about 150 feet. It can be seen best in the Wiarton road-cut. The upper member can be seen in the Cook quarry at Wiarton, underlying the Guelph Formation.

The Guelph Formation is also a reefal complex. It is similar in many ways to the Amabel Formation, but is more reefal (to an even greater degree). Biohermal, interbiohermal, bedded clastic flank deposits and knoll-interknoll facies are known. Detailed descriptions are included in the discussion of the Guelph in Bolton and Liberty (1955).

The (Guelph) formation ranges from 100 to 170 feet in thickness. It may be seen north of the Wiarton road-cut above the level of the Campbell Monument, and in the Cook quarry, west of Wiarton."

Williams (1919, p.70) accounts for the abundance of reefs in the Amabel Formation as follows:

The higher dolomites were deposited in wide-spreading seas, which were of such depth and temperature as to promote the growth of coral reefs even within the Arctic regions. A partial emergence of the land caused an inflow of sufficient detrital material to give the Eramosa beds their argillaceous and arenaceous character, these beds being deposited against and over coral reefs whose development they arrested. This period of diminishing seas closed Niagara time, the succeeding deposits being Guelph.

Sources of Further Information

In addition to the exposures of Guelph - Lockport - Amabel rocks previously mentioned, outcrops are indicated on maps by Caley (1945) and Liberty (1966). Reports by Williams (1919, p.57-76) and Bolton (1957 p.44-59) give detailed descriptions of the formations and many of the outcropping sections.

The maps by Liberty (1966) also show locations of wells drilled in the course of oil and gas exploration. A library of rock-cuttings, including samples from many of the holes shown on these maps, is maintained in the Geological Survey Building in Ottawa. A catalogue of holes for which sample cuttings are available was prepared by Sanford (1964).

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